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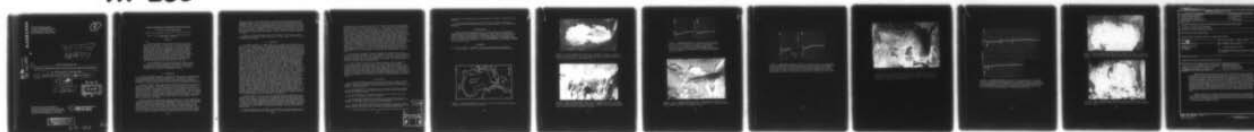
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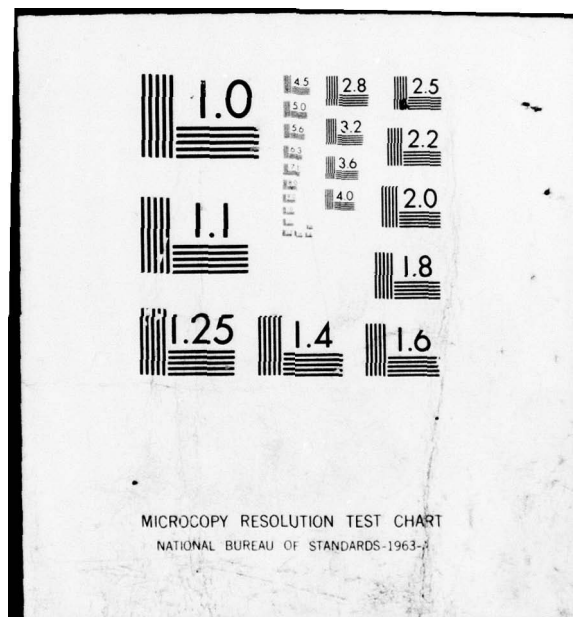


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Technical Report No. 255

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June 1977

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13 p.

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Reprint from the Proceedings of
the 11th International Symp. on Remote
Sensing of Environment, 25-29 April 1977,
University of Michigan, pp. 1609-1618.

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Office of Naval Research
N00014-75-C-0192
Project NR 388 002

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SURFACE TEMPERATURES AND TEMPERATURE GRADIENT FEATURES

OF THE U.S. GULF COAST WATERS

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ABSTRACT

✕
Satellite thermal infrared data on the Gulf of Mexico show that a seasonal cycle exists in the horizontal surface temperature structure. In the fall, the surface temperatures of both coastal and deep waters are nearly uniform. With the onset of winter, atmospheric cold fronts, which are accompanied by dry, low-temperature air and strong winds, draw heat from the sea. Penetrative convection and wind-driven mixing lower temperatures, first in the shallowest waters and then, as the winter season progresses, in deeper and deeper portions of the Gulf. A band of cooler water forming on the inner shelf expands, until a thermal front develops seaward along the shelf break between the cold shelf waters and the warmer deep waters of the Gulf.

Digital analysis of the satellite data has been carried out in an interactive mode using a minicomputer and software developed at the Coastal Studies Institute. A time series of temperature profiles illustrates the temporal and spatial changes in the sea-surface temperature field.

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1. INTRODUCTION

The most fundamental property of coastal and shelf waters routinely available from remote-sensing systems is temperature. The data are limited to surface temperatures only, but the prominent surface expression of important processes (coastal oceanic fronts, river and estuarine discharge plumes, and conditions of strong vertical mixing) make these data fields particularly useful.

A series of images acquired by the NOAA satellites has been obtained (in image and tape format). The images span the time from early fall to mid-spring. These data are products of the thermal sensors in the Very High Resolution Radiometers (VHRR). The spatial resolution of these scanners is 0.9 km at the satellite subpoint and degrades to 1.5 km at the image margin. Maximum thermal resolution is 0.5K. Thermal infrared images of any particular area are acquired every 12 hours, and a visual image is acquired once every 24 hours. In all the images the warmer-scene temperatures are represented by the darker gray shades. The data reveal the response of the coastal waters to the passage of winter-season atmospheric cold fronts.

The satellite data show highly organized patterns of surface temperatures, strong thermal fronts, and many complex gradient features. River and estuarine discharges, coastal and shelf waters, offshore gulf water, and the Loop Current show up as thermally differentiated water masses. The Loop Current is the stream of warm equatorial water that enters the Gulf of Mexico through the Yucatan Channel. After entering the Gulf it makes a broad curved 180° turn, exits through the Straits of Florida, and becomes a source of the Gulf Stream. With the exception of the thermally conservative Loop Current and the already chilled riverine discharges, the coastal and continental shelf waters undergo

important changes. These are primarily alterations in horizontal and vertical temperature structure initiated by the cold, dry continental air behind the atmospheric polar fronts. The coldest waters occur in the estuaries and along the inner shelf; the waters become progressively warmer offshore in the deeper portions of the Gulf. The shallow waters of the shelf are generally well mixed and the sea surface temperature is the same as that of the vertically uniform water column (Etter and Cochrane, 1975). The fall and spring months are times of transition between these two extremes of heat content and surface temperature gradients.

Figure 1 is an outline map of the Gulf of Mexico. The location of the continental shelf break is indicated along the northern coast of the Gulf by the 100-meter depth contour.

2. DISCUSSION

The NOAA-5 image for 1 October 1976 (Fig. 2) shows the conditions that are typical of the summer season. The surface temperatures of the coastal bays and shelf waters are the same as the temperature of the deep water of the Gulf of Mexico. Historical oceanographic data show that subsurface temperatures during the warm summer months are also uniform horizontally (Etter and Cochrane, 1975). By 11 October 1976 (Fig. 3) the first major cold front of the season had moved across the Gulf Coast. The air behind this front was much colder, and nighttime temperatures up to 7.5°C lower than those prevailing earlier in the season were measured at several coastal weather stations. The result of this initial outbreak of cold air was the lowering of the surface temperature of the coastal lakes and bays. The cool estuarine discharge of plumes overrunning the still-warm inner shelf waters shows up on the imagery; the maximum thermal contrast occurs at this point in the winter season. Offshore, horizontal temperature gradients still remained very weak. Along the shelf east of the Mississippi River the warm offshore water extended to the coast. West of the Mississippi River, cooler water was present tens of kilometers offshore. This difference between the regions east and west of the river is a consequence of the much shallower water on the shelf along the Louisiana coast. As a cold, dry air mass passes over the Gulf waters, energy is transferred from the ocean. Long-wave radiation is readily transmitted through the clear skies into space. Sensible and latent heat transferred to the atmosphere by conduction and evaporation at the water surface are carried upward by turbulent air motions. Persistent offshore winds sweep this heat and water vapor seaward, and dry air is replenished from the land. Aided by the wind stress, the increase in density of surface waters resulting from heat loss and evaporative salinity increase initiates penetrative convective mixing, which dissipates stratification, and the surface temperatures become more representative of the resulting isothermal water column. Because the amount of temperature decrease depends upon depth, the shallowest regions experience the largest temperature drop. Surface temperature profiles extracted from the digital tapes for the NOAA-5 image of 11 October 1976 are shown in Figure 4. Figure 4a is the profile of line A-A' in Figure 3. Three temperature regions are evident: the cold bay waters, the slightly warmer nearshore waters, and the as yet uncooled offshore waters. The profile (B-B') from the Florida coast (Fig. 4b) shows the relatively uniform surface temperatures. Note that no attempt has been made to correct the satellite-observed temperatures for atmospheric attenuation.

The next phase, the winter cycle, is represented by an image taken on 18 January 1977 (Fig. 5). At the time this image was acquired the coastal waters of the Florida shelf had cooled and a temperature front was situated approximately 30 km offshore. The cooling of the water column that had occurred much earlier west of the Mississippi was beginning along the Florida coast. Figure 6 contains the surface temperature profiles extracted from the NOAA-5 image of 18 January 1977. Two temperature regions are evident in this image along the Florida coast (profile B-B'): cooled nearshore waters and the still-warm offshore waters.

With the passage of a succession of cold fronts, the band of cooler inner shelf waters forming along the coast expands until an oceanic thermal front

develops between the cold shelf waters and the warmer deep Gulf waters approximately along the 100-meter isobath (Fig. 1). This condition is illustrated by the NOAA-3 image of 13 February 1976 (Fig. 7). The synoptic sea surface temperature pattern at this time was divided into three distinct zones: the cold shelf waters, the warmer open Gulf waters, and, warmest of all, the Loop Current. Mesoscale irregularities had developed along the thermal front between the shelf waters and those of the open Gulf. The origin of these features is as yet unclear. Possible mechanisms include horizontal eddy motion, intrusions of surface water driven by strong winds, and overrunning by strong offshore currents. Another possible cause of excursions of the warmer water toward the coast could have been internal density cascading. This process involves down-slope flow of the colder and hence denser water that had formed on the shelf and a compensating landward flow of warmer offshore surface water. The shallow water of the Bahama Banks had also been cooled and was distinctly outlined in this image. The profiles in Figure 8 are taken from the NOAA-3 image of 13 February 1976. Profile A-A', from off the Louisiana coast, shows evidence of three temperature regions. The profile from off the Florida coast (B-B') is more complex owing to the presence of the mesoscale irregularities, as seen in Figure 7.

The continued outbreaks of polar continental air masses over the Gulf during the winter of 1976-77 caused the temperature patterns of the Gulf waters to evolve an additional step. By 1 March 1977 (Fig. 9) the gradient between the shelf and the deep Gulf waters had broken down. Strong cold fronts had significantly chilled the entire northern part of the Gulf, and only the equatorial waters of the Loop Current remained warm.

As the strength of the polar air masses decreases, with the advent of spring, the Gulf water begins to warm. The first waters that respond to the warming trend are the shallow waters in the coastal lakes and bays and along the shoreline. The NOAA-3 image of 24 April 1976 (Fig. 11) shows this warming along the Florida coast. The surface temperature of the bays along the northwest coast was warmer than that of the nearby Gulf water. The shallow banks in the Bahamas also had higher sea-surface temperatures than the adjacent Atlantic Ocean water. As the length of the days increases and the air temperatures rise, the waters of the Gulf will return to the warm-season conditions of Figure 1.

3. CONCLUSIONS

1. Surface temperature patterns of the Gulf of Mexico display a highly organized character. During the winter months three distinct regions are present: the cold shelf waters, the warmer deep Gulf waters, and the equatorial waters of the Loop Current.
2. A seasonal cycle of progressive cooling changes the uniform surface temperature distribution of the summer months into the thermally structured surface of the winter season.
3. The locations of the thermal oceanic fronts are controlled by the bathymetry; the shallowest areas cool quickest.
4. The shallow coastal lakes and bays are the first areas to show a response to both heating and cooling and therefore serve as indicators of the direction of the heat fluxes between ocean and atmosphere.
5. Poorly understood mesoscale irregularities occur along the oceanic thermal fronts. Sources of these features are uncertain because of the coarse spatial and temporal resolution of previous oceanographic measurements.
6. Surface measurement programs, guided by real-time satellite infrared

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observations, are suggested to aid in resolving the sources of frontal irregularities.

7. During the winter season the Loop Current is readily discernible because of the maximum thermal contrast that exists between it and the adjacent Gulf water.

ACKNOWLEDGMENTS

This research was performed under a contract between the Geography Programs, Office of Naval Research, Arlington, Virginia 22217, and the Coastal Studies Institute, Louisiana State University. Appreciation is extended to Mr. Jack Klein and Mr. Larry Breaker, of the NOAA/NESS Satellite Field Services Station, Redwood City, California, to Mr. Frank Kniskern, of NOAA/NESS, Washington, D.C., and to Dr. Stephen Baig, of the NOAA/NESS SFSS, Coral Gables, Florida, for the satellite data.

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Etter, P. C., and J. C. Cochrane, 1975, Water temperature on the Texas-Louisiana shelf. Texas A & M Marine Advisory Bulletin TAMU-SG-75-604.

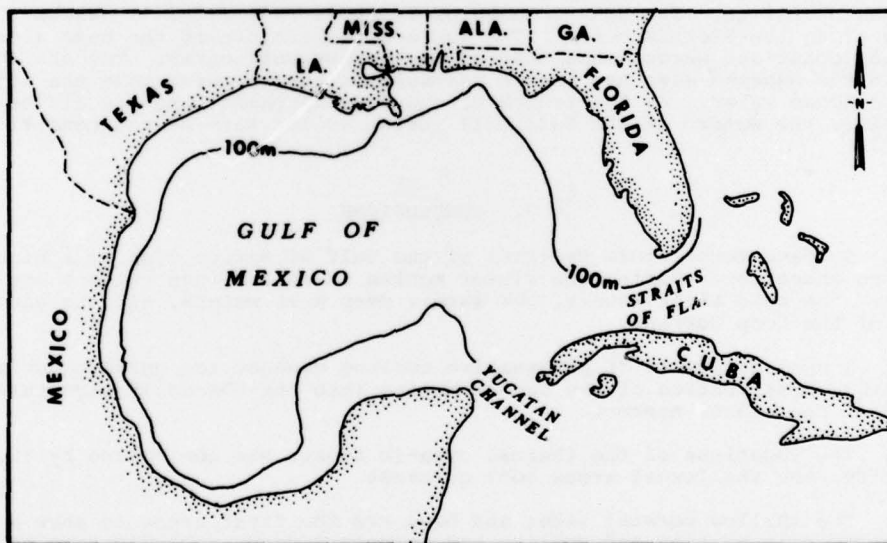


FIGURE 1. THE GULF OF MEXICO. The location of the continental shelf break is indicated by the 100-meter depth contour.

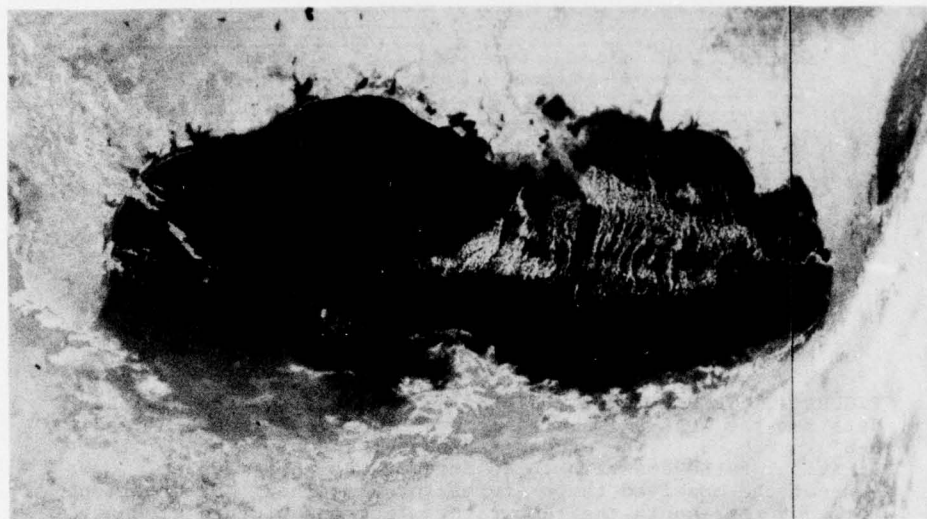


FIGURE 2. NOAA-5 INFRARED IMAGE, ORBIT 785, 1 OCTOBER 1976, 0225Z. Acquired shortly after the passage of an early-season cool front. Surface temperatures of coastal and deep waters are uniform; no strong thermal gradients exist. This image is representative of summer conditions.

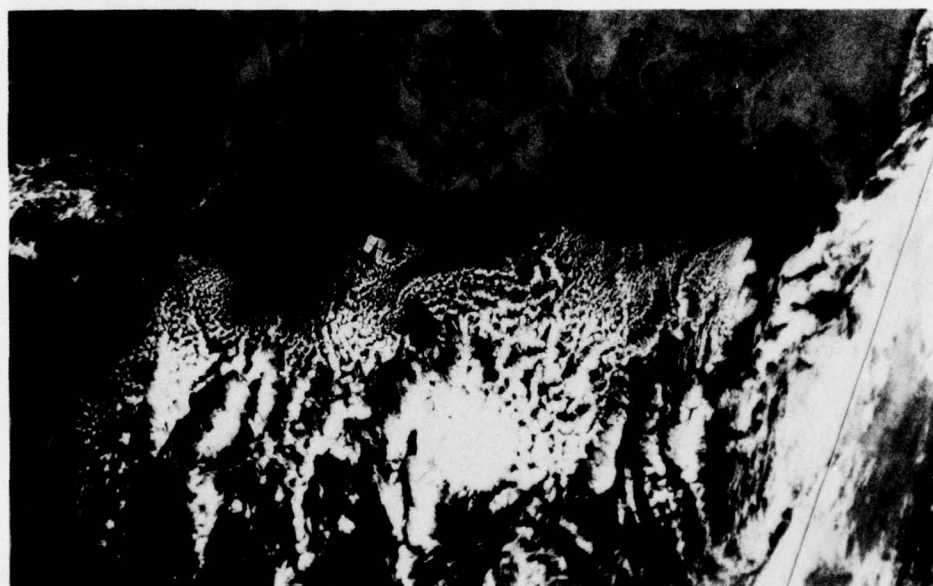


FIGURE 3. NOAA-5 INFRARED IMAGE, ORBIT 915, 11 OCTOBER 1976, 1500Z. Acquired after the first strong cold front of the season. Coastal lakes and bays chilled. Estuarine discharge plumes thermally distinct. Offshore cooling along Louisiana coast and weak horizontal temperature gradients.

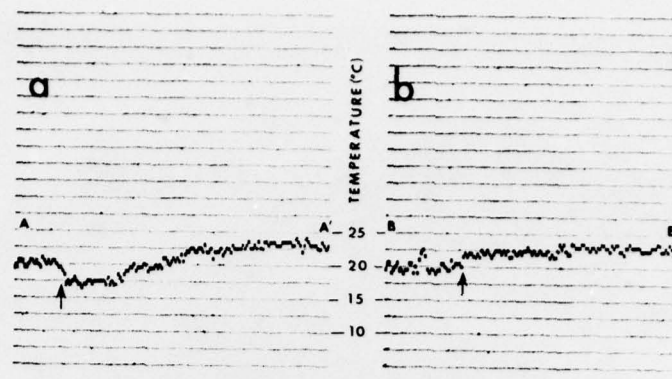


FIGURE 4. TEMPERATURE PROFILES. Extracted from the digital data for the NOAA-5 image of 11 October 1976 (lines A-A' and B-B' in Fig. 3). The arrows indicate the approximate location of the coastline. No attempt has been made to correct the observed temperatures for atmospheric attenuation. Each dot represents the temperature from one picture element along the lines.



FIGURE 5. NOAA-5 INFRARED IMAGE, ORBIT 2134, 18 JANUARY 1977, 0204Z. Sharp thermal gradient formed off Florida coast as a result of heat loss by the shallow water column. Continuation of offshore cooling.

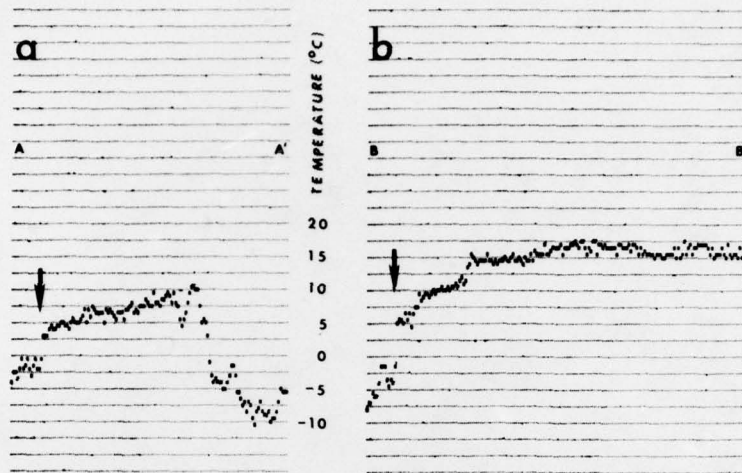


FIGURE 6. TEMPERATURE PROFILES. Lines A-A' and B-B' in Figure 5. Extracted from the digital data for the NOAA-5 image of 18 January 1977. The temperatures off the Florida coast (Fig. 6b) show the effect of the negative heat fluxes. Waters near the coast are cooler than those offshore, where depth is greater. Temperatures off the Louisiana coast are also cooler nearshore, but there is no sharp gradient offshore. Location of the coastline is indicated by the arrows.



FIGURE 7. NOAA-3 INFRARED IMAGE, ORBIT 10267, 13 FEBRUARY 1976, 0157Z. Strong negative heat fluxes affect the entire Gulf region, including the Bahamian and Cuban banks. Water in all shallow regions becomes cold. Three water types defined: cold shelf and coastal waters, cool Gulf waters, and warm equatorial waters in the Loop Current and Gulf Stream.

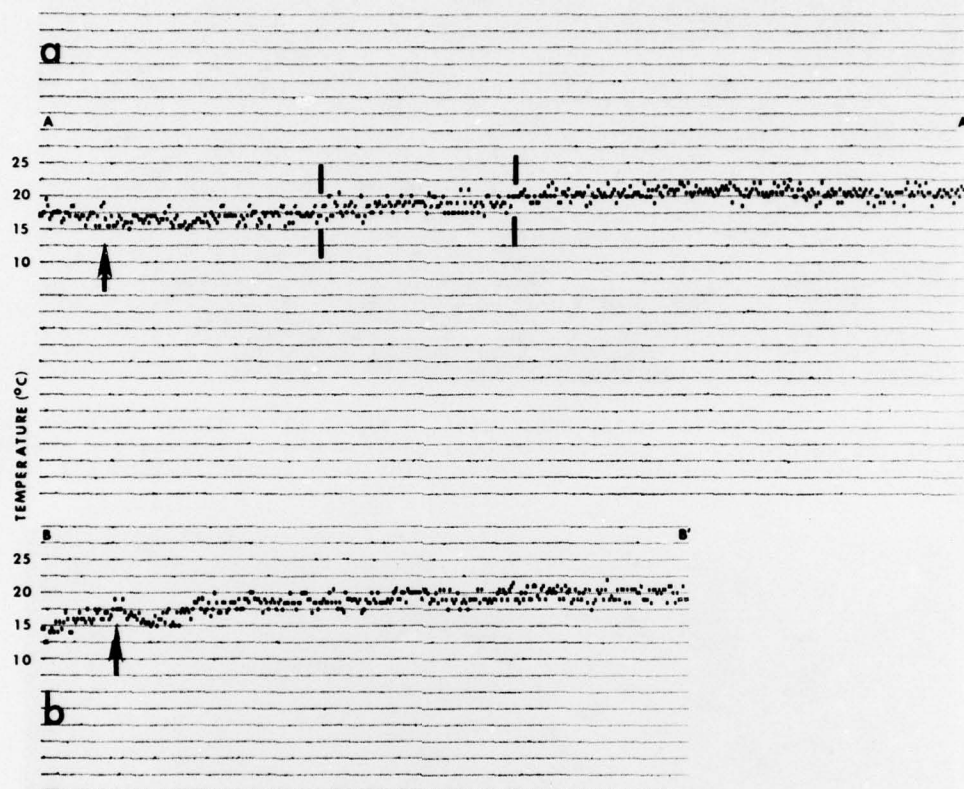


FIGURE 8. TEMPERATURE PROFILES, Lines A-A' and B-B' in Figure 7. Extracted from the digital data for the NOAA-3 image of 13 February 1976. The two vertical lines in profile A-A' approximate the locations of the gradients between the three temperature regions that are evident off the Louisiana coast (Fig. 7). Off the Florida coast (profile B-B') there does not seem to be such a separation. Location of the coastline is indicated by the arrows.

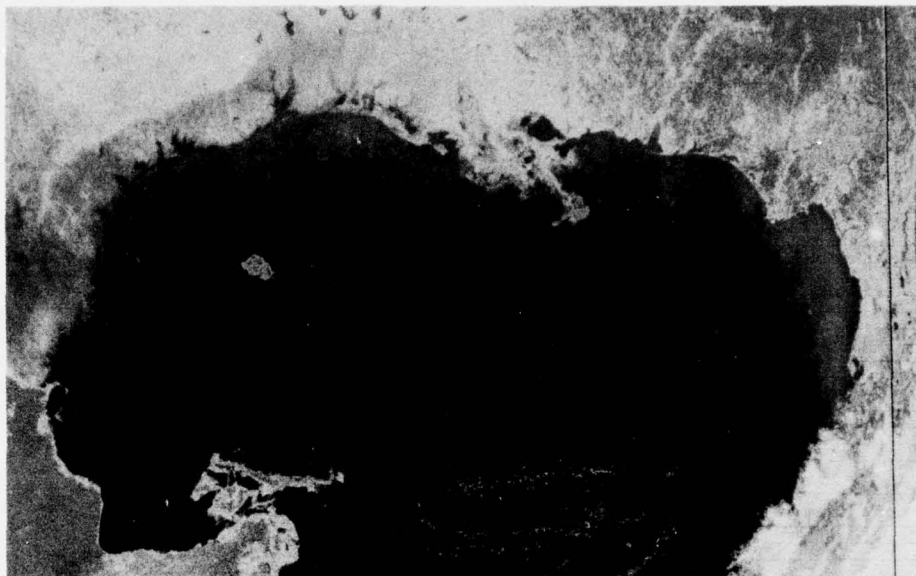


FIGURE 9. NOAA-5 INFRARED IMAGE, ORBIT 2654, 1 MARCH 1977, 0218Z. Strong cold fronts of the severe winter continue to cool shelf and Gulf waters, and thermal contrast at the shelf decreases. Eddies from the Loop Current extend far to the north.

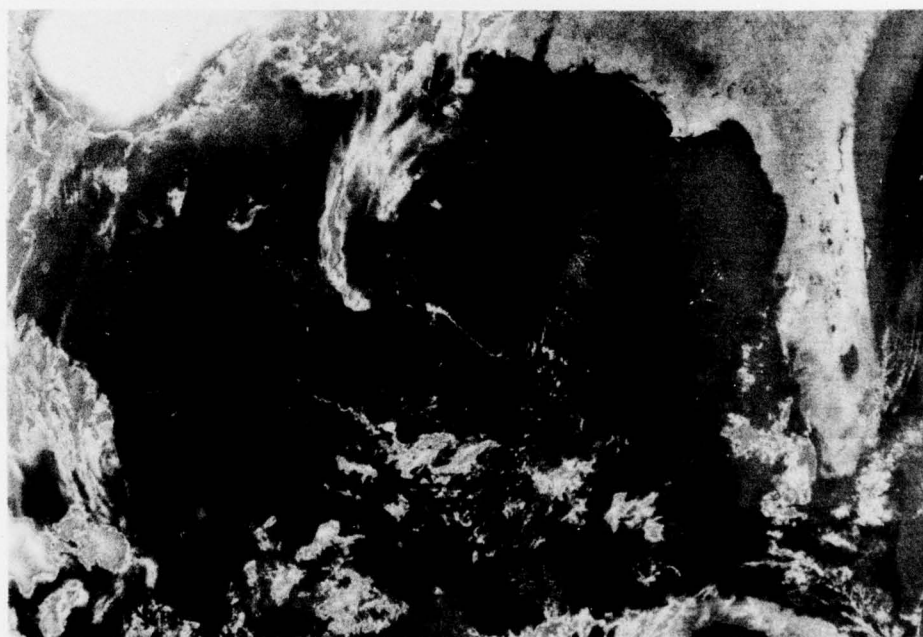


FIGURE 10. NOAA-3 INFRARED IMAGE, ORBIT 11085, 19 APRIL 1976, 0158Z. Warming of shallow regions along the Florida coast; evidence of positive heat flux along the inner shelf.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Coastal Studies Institute Louisiana State University Baton Rouge, Louisiana 70803		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP Unclassified	
3. REPORT TITLE SURFACE TEMPERATURES AND TEMPERATURE GRADIENT FEATURES OF THE U.S. GULF COAST WATERS			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)			
5. AUTHOR(S) (First name, middle initial, last name) Oscar K. Huh, Lawrence J. Rouse, Jr., and Glenn W. Smith			
6. REPORT DATE June 1977		7a. TOTAL NO. OF PAGES 10	7b. NO. OF REFS 1
8a. CONTRACT OR GRANT NO. N00014-75-C-0192		9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report No. 255	
b. PROJECT NO. NR 388 002			
c.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.			
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.			
11. SUPPLEMENTARY NOTES Reprint from the Proceedings of the 11th International Symp. on Remote Sensing of Environment, 25-29 April 1977, University of Michigan, pp. 1609-1618.		12. SPONSORING MILITARY ACTIVITY Geography Programs Office of Naval Research Arlington, Virginia 22217	
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DD FORM 1473 (PAGE 1)
1 NOV 65
S/N 0101-807-6811Unclassified
Security Classification

A-31408

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
remote sensing Gulf of Mexico temperature gradients water surface temperatures						